

# Brownfield Redevelopment Evaluation on the Abandoned Chemical Plant in Wuxi City

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**Abstract**-The objective of this paper was to establish a complete evaluation index system on brownfield redevelopment, a case study of the Former Huishan Pesticide Factory in Wuxi City, China. In this paper, we used the Extreme Condition Method, the Fuzzy Comprehensive Evaluation Method and the AHP. Land suitability evaluation index system was successfully developed based on concentrations of soil pollutants considering the human health. The index system may be reused for residential, entertaining, commercial and industrial sites from the perspective of ecological, social and economic conditions. Results showed that the Former Huishan Pesticide Factory Brownfield could turn into residential sites, commercial sites and entertaining sites, which was entirely consistent with the actual planning. To carry out a rational and efficient layout, we advised the Former Huishan Pesticide Factory Brownfield to be turned into residential sites and commercial sites first and then entertaining sites. Besides, remediation methods could be adjusted according to the planning of land use in order to achieve the maximum benefits. The conclusion was that the suitability evaluation of brownfield redevelopment through combining the Land Suitability Class with the Construction Land Suitability Class was viable and effective.

**Keywords**-Evaluation index system; Abandoned chemical plant; Wuxi city

## I. INTRODUCTION

With the industrialization, urbanization and urban industrial structure adjustment, resources and environmental problems have been emerged gradually. Cities launched a massive transformation and a large number of enterprises have been gradually relocated, thus leaving a lot of contaminated, abandoned and idle land which is called the brownfield in the western countries (Sousa C.D. 2001; Grimskid et al. 2001; Christopher W. G et al. 2007). Most of these brownfields were located in urban areas and contaminated by both heavy metals and organic pollutants (Alker, et al. 2000; Cao et al. 2007).

Brownfield redevelopment is conducted to protect land resources, to achieve the safety of environment and human health and to realize land resources sustainable use. To control and reuse the brownfield is of a great practical significance. Many experts and scholars have gradually recognized the importance of brownfield redevelopment (Ye C. et al. 2007), but the study of brownfield redevelopment has just started in China.

To redevelop the brownfield could reuse the previously abandoned land and protect the new development in limited arable land resource (Ellerbusch F. 2006; Zahra M. et al. 2009). It may be good for the protection and sustainable use of the land resources and the security of the regional ecological environment and human health. The brownfield control and reuse had a great practical significance in China (Wallace S. 2004; Cao K. et al. 2007; Bernard V. 2007).

The brownfield redevelopment suitability evaluation should follow the sustainable land use theory and location theory first. In addition, it needed to use the theory of the land economics, ecological economics and landscape ecology, to consider the issue of the land carrying capacity, land resources health and land ecological security and to strive to make the eco-efficiency, and social and economic harmonious development.

The land suitability evaluation was the basis of proper utilization of land resources. It played a positive role in guiding the land use planning (Shi T. G. et al. 2007). The studies on the land suitability evaluation in China had developed rapidly since 1970s when the principles and methods of the land suitability evaluation were proposed by FAO (Zhou L. S. 2006). The present paper discussed the possible patterns of brownfield redevelopment on a case study of the Former Huishan Pesticide Factory in Wuxi City from the pointview of land suitability.

The Former Huishan Pesticide Factory was located in Huishan district in Wuxi city. It was built in 1964 and it stopped its production because of the lack of proper environmental protection, which resulted in rapid deterioration of local ecological environment in 2005. Accordingly, the local land was seriously contaminated and the normal life of residents in surrounding areas was threatened. Therefore, the remained land of the Former Huishan Pesticide Factory was a typical brownfield.

The Fuzzy Comprehensive Evaluation Model (A. K. Braimoh et al. 2004; E. Audsley et al. 2008) was used in this paper to calculate the weight of land suitability. The land suitability evaluation included the suitability of residential sites, commercial sites and entertaining sites, which was consistent with the results of Municipal Planning Bureau.

The present paper includes nine sections: the determination of the evaluation system (Sect. 2), the division of the evaluation unit (Sect. 3), the determination of the evaluation approaches (Sect. 4), the construction of the indicators (Sect. 5), the suitability evaluation of brownfield redevelopment (Sect. 6), the determination of the suitability (Sect. 7), the conclusion (Sect. 8) and the acknowledgements (Sect. 9).

## II. THE DETERMINATION OF THE EVALUATION SYSTEM

Under the framework of this Brownfield Redevelopment Suitability Evaluation, the Land Suitability Class and the Construction Land Suitability Class was the basis of the whole evaluation process. Combining the two evaluations resulted in the Brownfield Redevelopment Suitability Evaluation. The types and concentrations of pollutants constituted the evaluation basis of the Land Suitability Class Determination where human health was the target. Thereby the

Land Suitability Class was divided into three categories: Class I, Class II and Unsuitability class (FENG, et al. 2009). The Construction Land Suitability Class was determined by three factors, which are ecological, social and economical effects. In each factor, it was evaluated by four possible redevelopment, which are residential-housing, entertainment, commercial-business and industry. According to the suitability, the Construction Land Suitability Class was divided into three categories: Class I, Class II and Class III (Zhang et al. 2009; Zhao et al. 2000). The Brownfield Redevelopment Suitability Evaluation System was summarized in Fig. 1 and the description of each evaluation factor for the Former Huishan Pesticide Factory is presented in Table I.

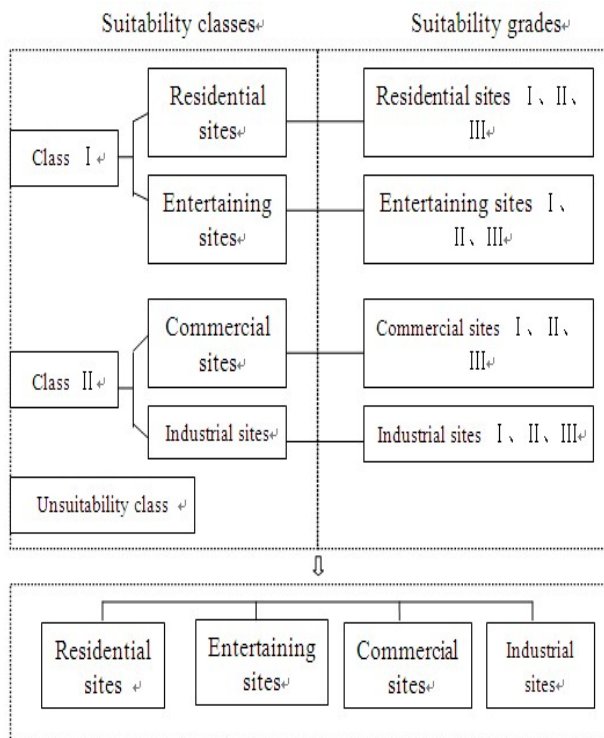


Fig. 1 The systematic diagram of brownfield redevelopment suitability evaluation

### III. THE DIVISION OF THE EVALUATION UNIT

The connotation of the Contaminated Land Restoration and the Construction Land Redevelopment were included in the activities of the brownfield redevelopment. The approaches of pollution reparation and the reuses and redevelopment of the land were affected by the conditions of soil pollution (Fisal et al. 2004). Therefore, the conditions of soil pollution should be considered at first in the division of the evaluation. But as the soil pollution map of the Former Huishan Pesticide Factory was not finished, there was limited data available and the brownfield reparation was a whole engineering project. This article regarded the Former Huishan Pesticide Factory as an evaluation unit.

### IV. THE DETERMINATION OF THE EVALUATION APPROACHES

The approaches of the Land Suitability Evaluation contain the Experience Method, the Extreme Condition Method, the Mathematics and so on (Zhou 2006). Considering the pollutants concentration would restrict the land use patterns, we selected the Extreme Condition Method to evaluate the Land Suitability Class. On the other hand, the evaluation of

the Construction Land Suitability Class may emerge the problem of subjectivity and ambiguity in many other evaluation factors and some are difficult to describe in accurate mathematics. Therefore, we select the Fuzzy Comprehensive Evaluation Method to evaluate the Construction Land Suitability Class. At last, we tested the consistency of assessments of the Land Suitability Class and those of the Construction Land Suitable Class, which finally resulted in the Brownfield Redevelopment Suitability.

## V. THE CONSTRUCTION OF THE INDICATORS

### A. The Indicators of the Land Suitability Class

There were hundreds of pollutants in the soil of the Former Huishan Pesticide Factory. The carcinogenic pollutants mainly contained DDT, Benzene, Xylene, Dichloroethane, Chloroform and Hexachlorobenzene. To these carcinogens, experts conducted the Human Health Risk Assessment through the oral intake, the skin touching and the inhalation touching. These carcinogens were characterized by their potency and volatility and human health was greatly affected by them. According to the general principles and the priority principles of the indicators selection, DDT and Benzene were considered as the evaluation factor of the Redevelopment Suitability Class in the Former Huishan Pesticide Factory. At the same time, we formulated a Brownfield Redevelopment Appropriateness Criteria which depended on the Soil Environmental Quality Evaluation Standards on Exhibition (interim) (HJ350-2007) and the Soil Environmental Quality Standard (GB15618-1995). The concentration of DDT was required to be less than or equal 1 mg/kg in class I and more than 1 mg/kg in both class II and unsuitability class. The concentration of Benzene was required to be less than or equal 0.2 mg/kg in class I and between 0.2 mg/kg and 13 mg/kg in class II and in unsuitability class, it may be more than 13 mg/kg.

Class I was the soil which could be exposed to the human being directly, which had a strict concentration of soil pollutants. This category soil could be turned into the residential sites and the entertainment sites which included Park, Green Square and Playground. Class II was the land use type which was not belonged to the Class I, it had higher concentrations of soil pollutants, which could be turned into the commercial sites and the industrial sites. Unsuitability Class was the soil which did not suit for any types of land reuse and it requires to be remediated before redevelopment and utilization.

### B. The Indicators of the Construction Land Suitability Class

The brownfield was usually produced in the suburbs of a city. It could be divided into the residential brownfield, the entertaining brownfield, the commercial brownfield and the industrial brownfield according to the use of the brownfield redevelopment (Wallace, Steve. 2004). The Construction Land Suitability Evaluation was evaluated separately on the four categories of usages. Then, the Construction Land Suitability Class may be determined. According to the connotation of the Brownfield Redevelopment Appropriateness Evaluation, "Urban Land Classification Order" (GB-T 18507-2001) and the principles of comprehension, system, science and appliance, we established the indicators of the Construction Land Suitability Class (Figure. 2).

TABLE I. DESCRIPTION OF EACH EVALUATION FACTOR OF THE FORMER HUIZHAN PESTICIDE FACTORY

Evaluation factors	Primary evaluation factors C	Second evaluation factors	Description
Ecological conditions	C <sub>1</sub>	Groundsill carrying capacity	Low soil compression and high carrying capacity is a good natural groundsill stratum. Groundsill carrying capacity standard is between 220 Kpa and 250 Kpa, the building of 12-15 floors in the region generally can use the natural groundsill.
	C <sub>2</sub>	Distance to ecological landscape	The shortest distance is 3 km away from the largest green park in Wuxi city—Huishan Forest Park with good environmental quality.
Social conditions	C <sub>3</sub>	Town planning	Land Use Planning of Qianqiao town (BE46-E0103-2007-003) was released by Huishan Land Bureau in Wuxi, which focused on tapping the potentials of construction sites. And the former Huishan pesticide factory was planned their land reuse for commercial and residential purposes.
	C <sub>4</sub>	Public receptivity	Public concerns on housing on the land included harmness to the health of residents. But most residents can accept the land reuse after the scientific remediation and restoration. It is difficult to accept to the public that building factories would generate waste pollution problems.
Economical conditions	C <sub>5</sub>	Condition of infrastructure	Hot water, telecommunications and other living installations are complete. Within a radius of 0.8 kilometers, there are farmers markets, schools (such as Qianqiao Central Primary School, Qianqiao Middle schools), hospitals (such as Qianqiao hospital, Qianqiao health service center), supermarkets (such as Yong-an Supermarket, Trust Mart Supermarket), theaters, banks, fitness, and other public installations.
	C <sub>6</sub>	No. of traffic lines	Total of five bus lines—k2, 15, 206, 4, 608 pass the recent bus stop—"Qianqiao New Street". Traffic line goes to Wuxi city, railway stations and South bus station directly. The bus stop—Qianqiao was located in the center of the town, where has eight bus lines.
	C <sub>7</sub>	Distance to freight center	The shortest driving distance is 10.4 kilometers away from big Wangji freight station of Wuxi Passenger Corporation and 10.2 kilometers from Hung-kun freight station. Urban land classification rules order services radius of external transport facilities between 2 and 20 km.
	C <sub>8</sub>	Distance to Industry Park	Straight-line distance is 1.8 km away from the nearest Industrial Park (Helu Industrial Park, Longshan Industrial Park and Wenbo Industrial Park).
	C <sub>9</sub>	Distance to city center	It is about 10 km away from the most prosperous regions of Wuxi City (the government as a landmark) and about 1.2 km away from the most prosperous regions of Qianqiao (Qianqiao bus station as a landmark).

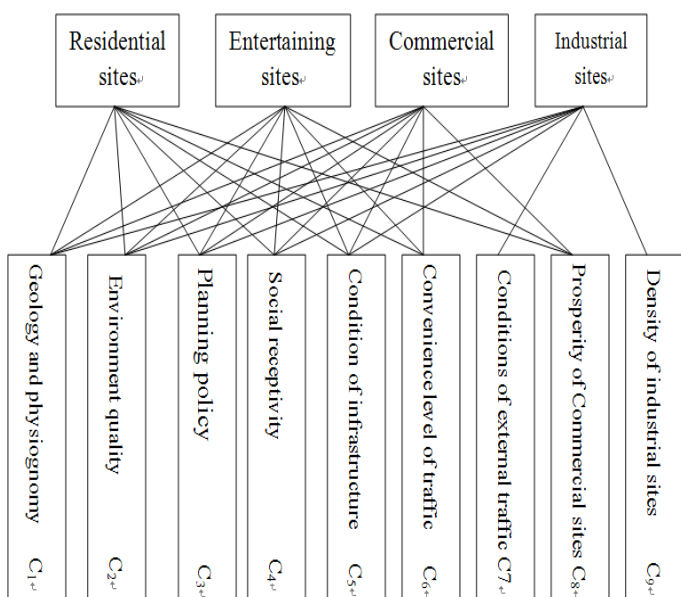


Fig.2 The evaluation index screening scope of different land use types

## VI. THE SUITABILITY EVALUATION OF BROWNFIELD REDEVELOPMENT

### A. The Screening of the Remediation Methods

After the closure of the Former Huishan Pesticide Factory, the site which was polluted by pesticides turned into a brownfield. It had health risks which could not be ignored and was in the Unsuitability Class. Therefore, we must first carry out the implementation of remediation works. The concentration of soil pollutants plays an important role in the brownfield redevelopment (W.J. Conover, et al. 2008; Ali Mosleha, et. al. 2009). So under the premise of soil conditions, we used the pollutant removal rate as the main factor to select remediation methods which had a higher removal rate (Mulligan C. N. et al. 2001).

DDT and Benzene belonged to the persistent organic pollutants. According to the previous reports, the Cement Kiln Disposal Act was a cost-effective method which had a higher removal rate (99.99%) (Luo C. Z. et al. 2008). Therefore this method could be selected as the remediation method for removing the Former Huishan Pesticide Factory Pollution.

### B. The Determination of Suitability Class

The pesticide pollution of the Former Huishan Pesticide Factory would be removed by the proposed remediation method. Considering concentration of soil pollutants, the restored evaluation unit and the principle of the Conditionality France, the suitability class of the Former Huishan Pesticide Factory was determined. The results showed that the suitability class of the Former Huishan Pesticide Factory Brownfield belonged to unsuitability class before remediation, while after a series of remediation, it may be Class I.

### C. The Determination of the Construction Land Suitability Class

#### 1) The Determination of the Weight

Taking the residential sites as an example; we invited 6 experts who grasped the ecological, social and economic situation of Qianqiao to scale the importance of every evaluation indicator in accordance from 1 to 9. After counting the data, we put them into the yaahp to treat with AHP. Simultaneously, they were carried out the consistency test. The index weight of the residence sites suitability evaluation was generated (Table II).

#### 2) The Determination of the Membership

To evaluate the Construction Land Suitability Class, we would have a combination of the qualitative and quantitative description (Table IV). Then we would invite 10 experts and some local residents to carry out the Fuzzy Evaluation to those descriptions. Table III was the result of the Fuzzy Evaluation.

#### 3) The Fuzzy Comprehensive Evaluation

The weight and the membership of the evaluation indicator were included into the DPS. Using the order of the Fuzzy Comprehensive Evaluation and selecting the  $M(-, \oplus)$ , the evaluation result of the Residence Sites Suitability Class was generated. Class "1" accounted for 0.7537, "2" accounted for 0.2463 and "3" accounted for 0.0000. Under the principle of the maximum, the residential sites belonged to class "1". The same approaches were used to evaluate the suitability of the entertaining sites, commercial sites and industrial sites (Table III)

## VII. THE DETERMINATION OF THE SUITABILITY

According to the evaluation results of the Land Suitability Class, the Former Huishan Pesticide Factory Brownfield fell into Class I. The site may be suited to be residential site. As the Class I had a more strict request of soil pollutants than the Class II in the process of the suitability class division, if a brownfield belonged to the Class I, it must also belong to the Class II, but if a brownfield fell into the Class II, it might not belong to the Class I. Therefore, the Former Huishan Pesticide Factory Brownfield might not only be reused as a residential site, but also be reused as an entertaining site, commercial site and industrial site.

According to the evaluation results of the Construction Land Suitability Class and the priority level, we knew that the Former Huishan Pesticide Factory Brownfield fell into the Class I of the residential site, the Class I of the entertaining site and the Class I of the commercial site simultaneously.

According to the frame of the Land Persistence Use and the evaluation results of the Land Suitability Class and the Construction Land Suitability Class, the Former Huishan Pesticide Factory Brownfield may be suited to be a residential, entertaining and business site. The values of the residential, entertaining and commercial sites were 0.7537, 0.7427 and 0.6566, respectively. Therefore, the Former Huishan Pesticide Factory Brownfield should be first considered to be reused as a residential site.

## VIII. CONCLUSION

The human health and land sustainable use of the Former Huishan Pesticide Factory were assessed from the perspective of the ecology, the society, and the economy. The evaluation results of the residential sites, commercial sites and entertaining sites reflected the objectives of land suitability evaluation of brownfield redevelopment. In fact, Planning Bureau allowed the Former Huishan Pesticide Factory Brownfield to be reused as a residential site and commercial site. It was consistent with the evaluation results of this study. This supported the right model selected and used in the present study to evaluate the suitability of brownfield redevelopment.

TABLE II. SUITABILITY FUZZY COMPREHENSIVE EVALUATION OF RESIDENCE SITES

Evaluation object A	Evaluation factors B	weighting	Primary evaluation factors C	weighting	Evaluation result		
					I	II	III
Suitability of residential sites	Ecological conditions B <sub>1</sub>	0.2970	C <sub>1</sub>	0.3333	1	0	0
			C <sub>2</sub>	0.6667	0.7	0.3	0
	Social conditions B <sub>2</sub>	0.1634	C <sub>3</sub>	0.6667	0.9	0.1	0
			C <sub>4</sub>	0.3333	0.7	0.3	0
	Economical conditions B <sub>3</sub>	0.5396	C <sub>5</sub>	0.4579	0.8	0.2	0
			C <sub>6</sub>	0.4161	0.6	0.4	0
			C <sub>8</sub>	0.1260	0.7	0.3	0

TABLE III. THE SUITABILITY EVALUATION OF CONSTRUCTION LAND OF THE FORMER HUIZHAN PESTICIDE FACTORY

Types of construction sites	Evaluation result of suitability class	subsection
Residential sites	I	0.7537
Entertaining sites	I	0.6566
Commercial sites	I	0.7427
Industrial sites	III	0.3653

The Former Huishan Pesticide Factory Brownfield may favorably be turned into the residential site and commercial site other than the entertaining sites to achieve a reasonable and efficient planning layout. To be the residential site and entertaining sites, a cost-effective remediation approach such as the Low-temperature Thermal Analysis Method could be employed to lower the contamination concentrations to the standards of Class I. But to be the commercial site, other more cost-saving remediation technology such as Bioventing may be used to increase the pollutant removal rate to the standard of Class II. Thus the maximum benefits of the reparation project could be achieved.

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